

Hydrogen & Natural Gas – What Does The Future Hold?



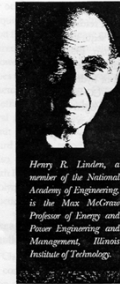
GTI Background

- GTI/IGT - Long Hydrogen History
 - Dr. Henry Linden & "Hydrogen Economy"
 - Vision of post-fossil-fuel economy
 - "A Hydrogen-Energy System," Dr. Derek Gregory (1972)
 - *Sponsored by AGA!*
 - Founding member of National Hydrogen Association
 - Over 40 Years Experience With Fuel Cells, Reforming & Gasification
 - Over 200 Hydrogen publications

Alternative Pathways to a Carbon-Emission-Free Energy System

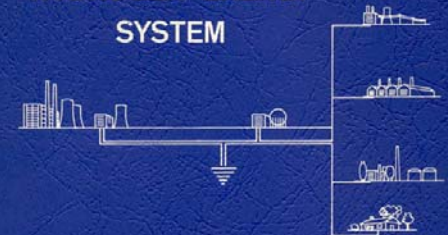
Henry R. Linden

There has developed a broad consensus that energy systems will move towards electricity for all stationary energy uses, and to hydrogen (compressed, adsorbed, or liquefied) for transportation fuel.



Over the past several decades there have been drastic changes in the perception of the forces driving the evolution of the global energy system. Technological advances and increased efficiency have calmed fears of large price increases and early exhaustion of the most desirable fossil fuels—oil and natural gas. In fact, during 1998, oil prices in deflated terms dropped to a 50-year low. Natural gas, although not nearly as fungible as oil, has become a widely traded commodity because of the growing importance of liquefied natural gas and the use of transnational pipelines to provide clean and cost-effective energy. In the era since 1997, profitability of gas

A HYDROGEN - ENERGY SYSTEM



GTI Gasification History



Shanghai, China GTI-UGAS Coal Gasification Plant



Temper, Finland GTI-RENUGAS Biomass Gasification Plant

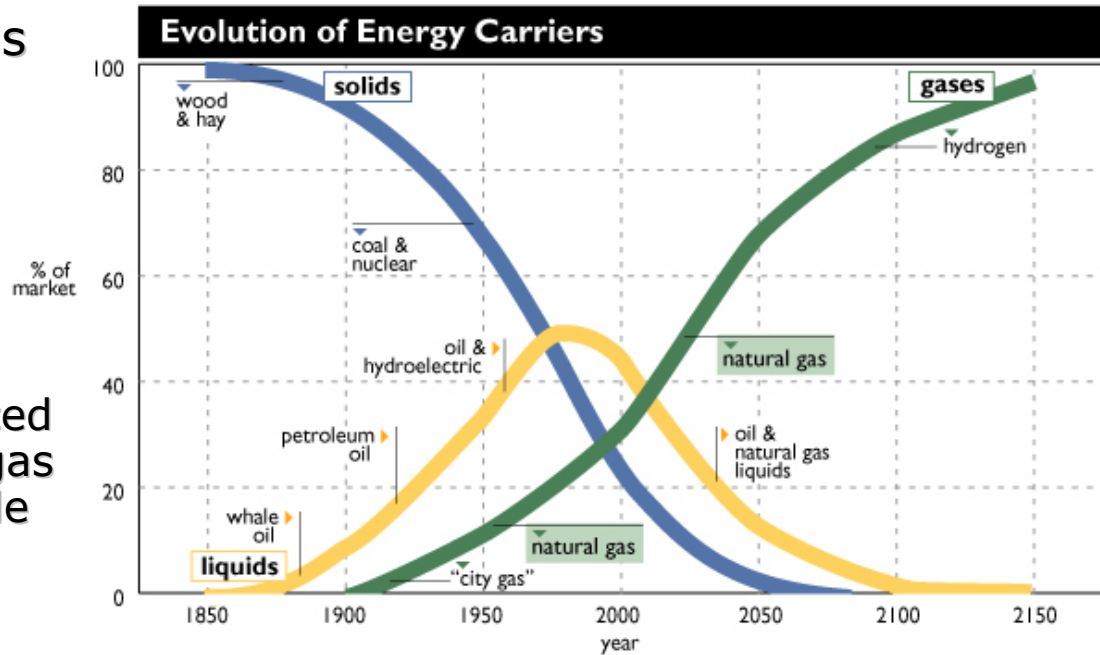


Hawaii GTI-RENUGAS Biomass Gasification Plant

Hydrogen & Natural Gas

■ Hydrogen & Natural Gas

- Long Connection
- Past: Manufactured Gas Plants
 - Using coal and other products to make synthetic natural gas
- Present: Hydrogen Source
 - Most hydrogen produced by reforming natural gas reforming in large scale plants
- Future: Part of Energy Evolution?



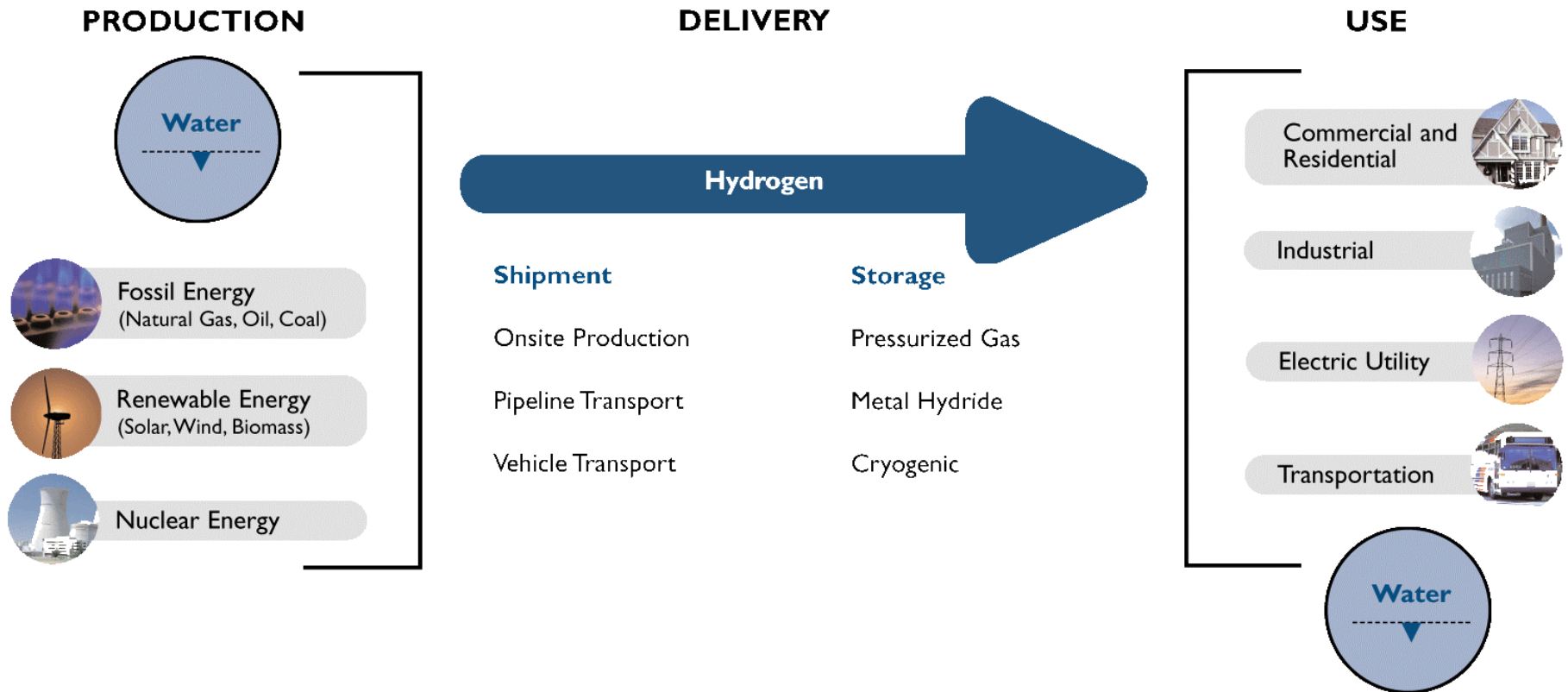
Modified from "The Economist", February 10, 2001 edition.

Hydrogen Situation Assessment

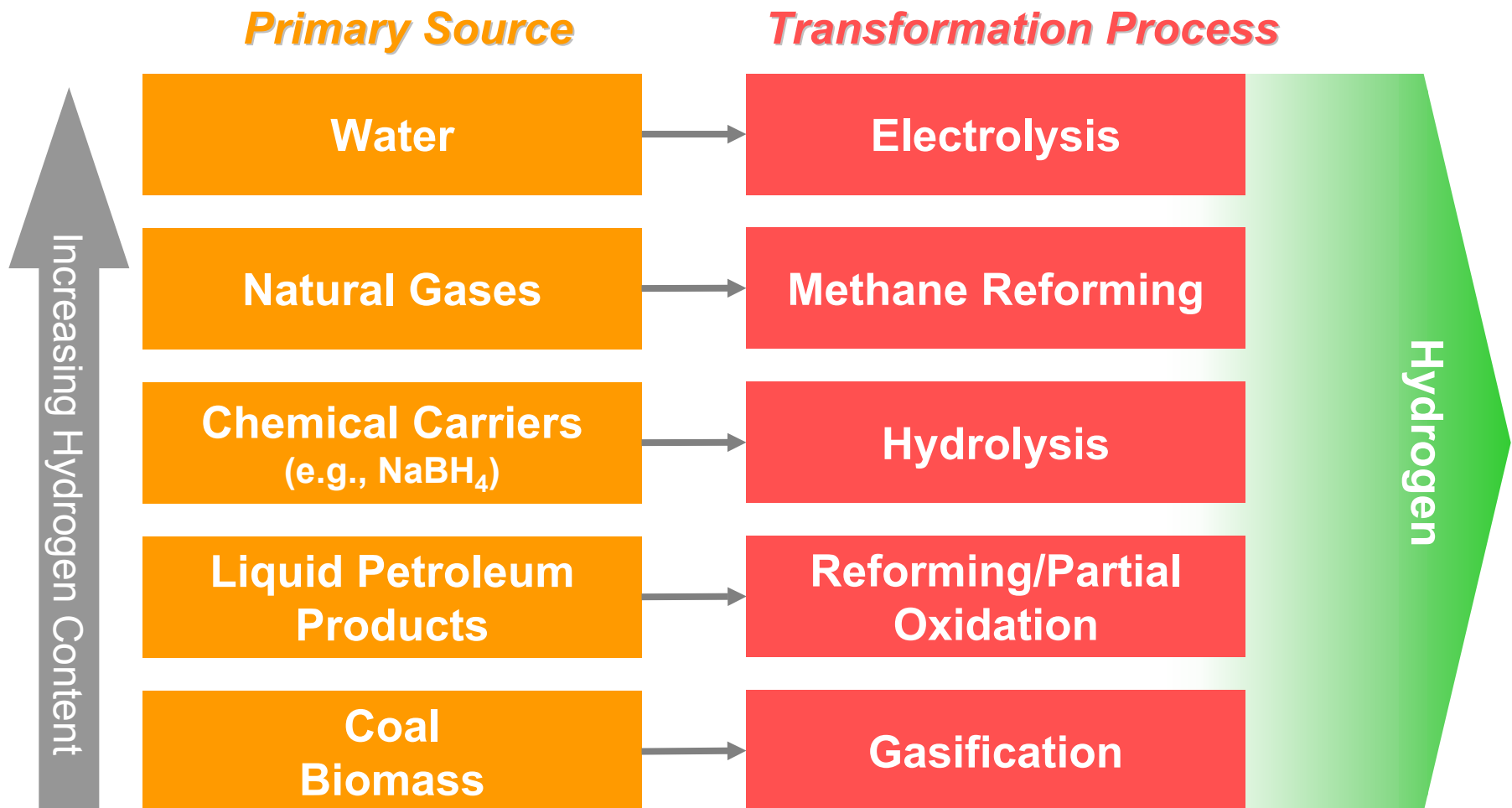
- Hydrogen Today Mainly An Industrial Chemical
 - Refinery Operations plus ammonia and methanol production
 - Some other small niches
- Immature Hydrogen Energy System
 - Limits in delivering hydrogen
 - Few “retail” markets
- Hydrogen in “Second Wave” of Interest
 - First wave from late 1960’s to late 1970’s
- Why The Interest Today?
 - Global Climate & Environmental Factors
 - Renewable & Sustainable Energy Solutions
 - New Uses - Fuel Cells



THE HYDROGEN ENERGY SYSTEM



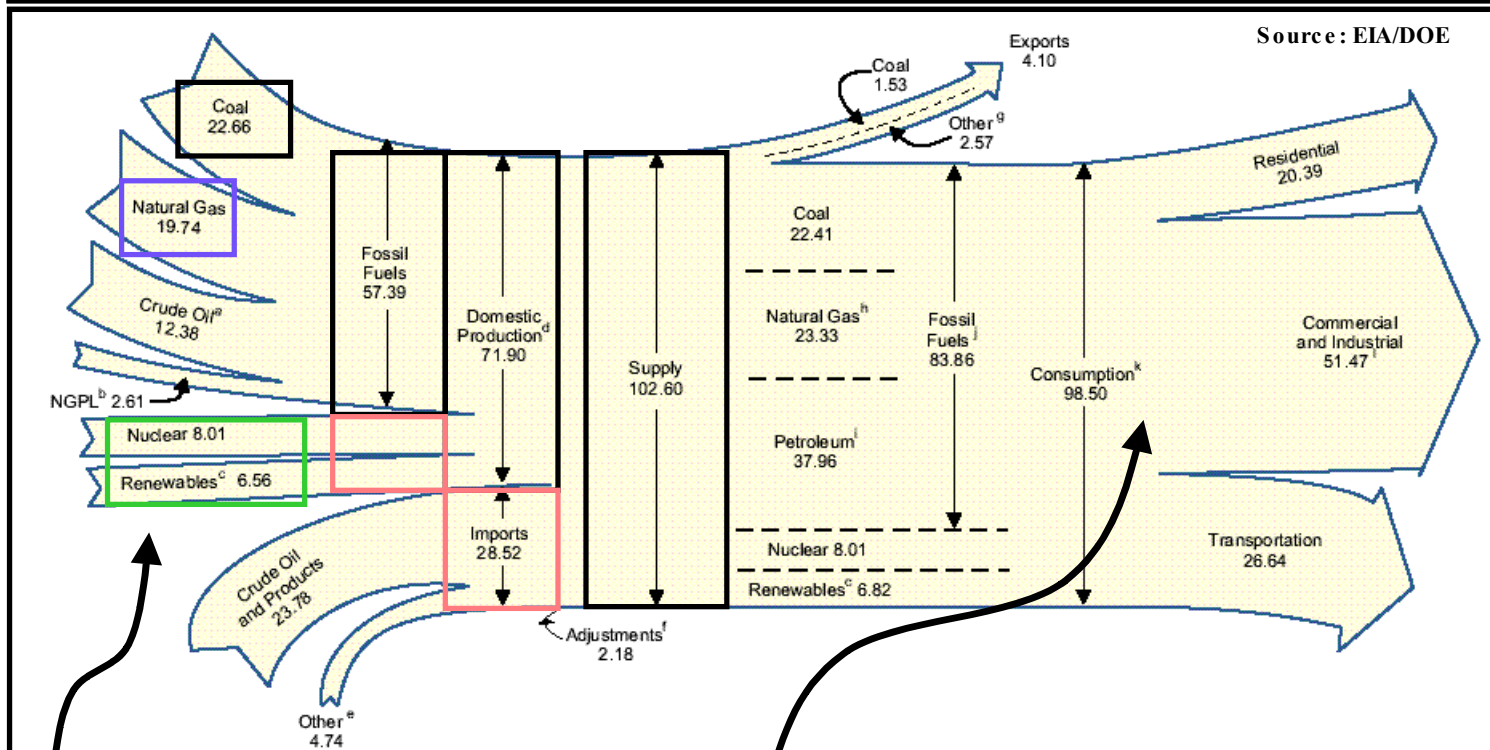
Hydrogen not naturally found. Must be made from primary energy sources and transformed...



Hydrogen in U.S. Energy Picture

Strategic Role: Decrease Imports, Increase Non-Fossil Fuel Use

Challenges: Decrease Cost, Create Value-Added Uses



● Hydrogen not a primary energy source. Can be made from a variety of other primary energy resources.

● Hydrogen an intermediate product or carrier – means of bringing energy to users. About 0.5% of energy flow now.

Transportation Market

- Vehicles are a key area for hydrogen
- Best opportunity for significant retail market
- Requires a number of major advancements
 - Fuel cell vehicles with demonstrated performance, efficiency, reliability, cold weather capability, and cost effectiveness
 - Development of a delivery and retail infrastructure
- Several pre-commercial vehicles expected during next few years
 - Toyota & Honda initially
- Emergence of fuel cell vehicles clouding NGV positioning
 - Some “passing over” option in lieu of “long-term solution”

GTI Hydrogen Fueling Systems

- Integrated Natural Gas to Hydrogen System
 - Sponsored by DOE
- Compact Natural Gas Reformer & Fuel Processing
- Fuel Purification
- Gas Compression
 - Uses FuelMaker units
- Hydrogen Dispensing
- Current System Sized at 50 kg/day
- Key Benefit: Onsite production uses natural gas infrastructure



GTI Integrated Hydrogen Fueling System



Hydrogen Fueling System Detail

GTI High-Pressure H₂ Test Facility

- Intrinsically Safe Large-Scale Environmental Chamber
- Three Bank, High-Pressure Hydrogen Cascade
 - 7,000 psig
- Wide Temperature Capability
 - -50 to 180°F
- Fully Instrumented, with High-Speed Data Acquisition System
- Wide Range of Tests Run on High-Pressure Hydrogen Cylinder Filling

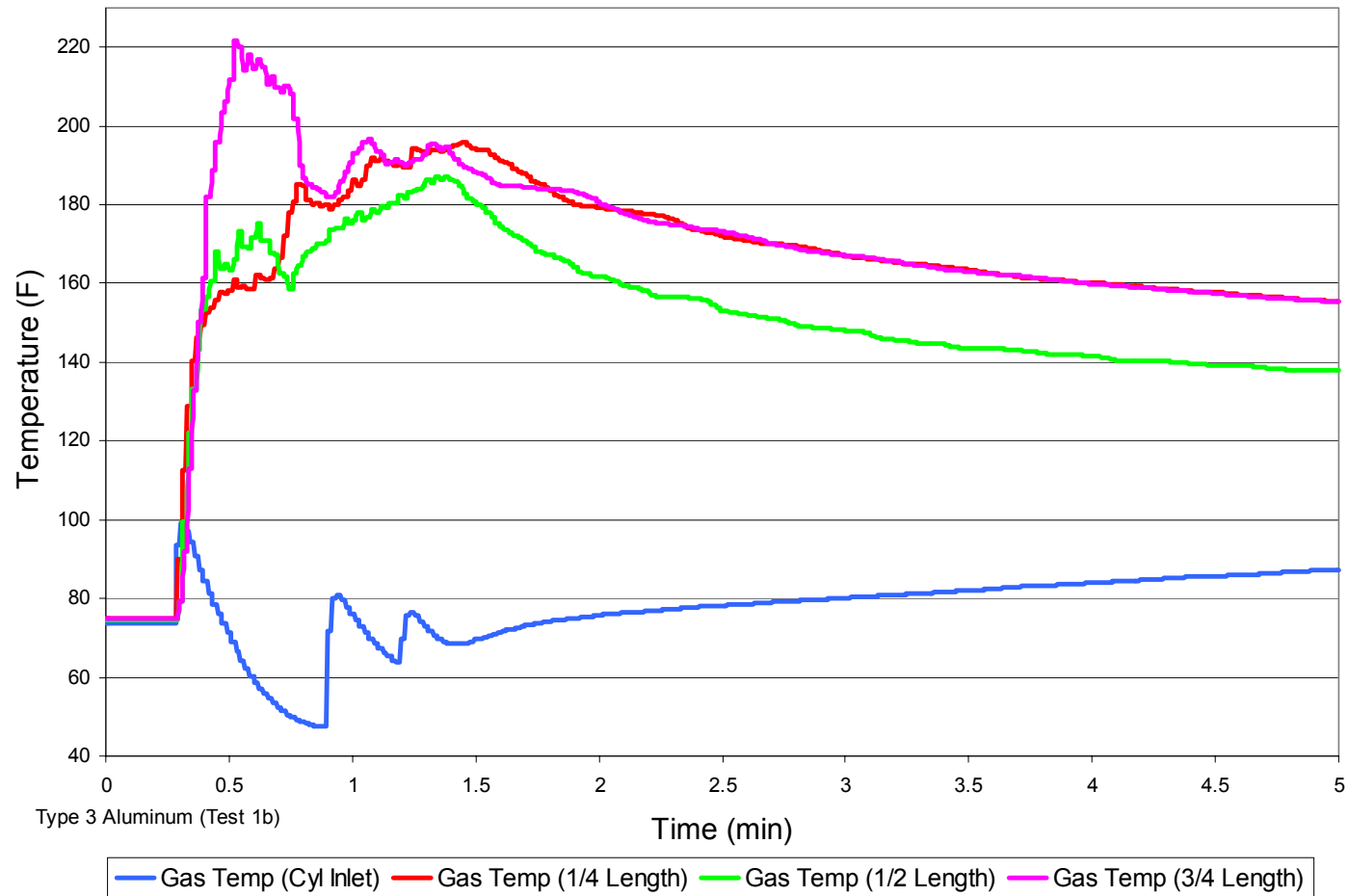


GTI High-Pressure Hydrogen Environmental Chamber



Instrumented H₂ Cylinder

Example Hydrogen Cylinder Filling



Leveraging Natural Gas & Hydrogen Infrastructure

- Interest in identifying options to “leverage” natural gas/NGV investments for hydrogen
 - Take advantage of current investments
 - Ensure new natural gas/NGV investments are not “stranded”
- Couple ways of looking at the issue
 - Hydrogen now leverages variety of NGV developments (storage cylinders, PRDs, compressors, dispensers, etc...)
 - Incremental cost to make new hydrogen products
 - Switching service on existing in-use products
 - Variety of issues make this concept expensive...
 - Hydrogen Upfittable
 - Can we do things to today’s products to make them usable for hydrogen in the future?

Summary

- Hydrogen Seen As Key Future Energy Carrier
- Primary Energy Source Remains Unclear
 - Natural gas likely to meet needs in foreseeable future
- Challenges To Hydrogen and H₂ Vehicles Numerous
 - Requires simultaneous breakthroughs in vehicle technology and infrastructure
 - Cost of fuel (\$/Btu) high and limited range
 - Makes NGVs look attractive
- Expect Long Period of Evolution
 - Current “hype” will subside as depth of issues become clearer
 - Will take 15-30 years to evolve vehicle and infrastructure technology
 - Remember, NGVs are now in about the 15th year of their second wave (beginning with introduction of Cummins L-10 transit bus engine in late 1980s)

